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Tillage and straw management impact on soil structure, compaction and soybean yield on fluvisol

Utjecaj obrade tla i malča na strukturu tla, zbijenost i prinos soje na fluvisolu

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ABSTRACT

Soil tillage management can have positive and negative short-term effect on agroecosystem. Therefore, searching for optimal tillage management is crucial for the maintenance and improvement of soil functions. The purpose of this study was to analyze the impact of conventional tillage (CT), minimum tillage (MT) and reduced tillage (RT) on Fluvisols in humid environments (Croatia). Under each treatment, subplots with and without straw were applied. The impact was assessed on physical soil properties and soybean (*Glycine max* (L.) Merr.) yield. Soil bulk density was significantly lower in RT with straw when compared to the other treatments. Straw significantly effected bulk density at 10-20 cm depth. Penetration resistance did not exceed the value of 2.5 MPa on any treatment, it was also significantly reduced on covered plots in Autumn. Soil water content showed higher values in straw treatments at MT and RT. Water stable aggregates percentage were high at straw plots and at MT and RT in addition to CT. Moreover, soybean grain yield was higher in straw plots at RT and MT. It can be recognized in the aspect of short-term results that the MT and RT is an advisable alternative for CT due to its positive impact on soil physical condition and grain yield.

Keywords: reduced tillage, straw mulch, soil physical properties

SAŽETAK

Primjena novog sustava obrade tla može imati pozitivan i negativan kratkoročni učinak na agroekosustav. Stoga, otkrivanje optimalne obrade je ključna za održavanje i pospješivanje funkcija tla. Svrha ovog istraživanja je analiza utjecaja konvencionalne (CT), minimalne (MT) i reducirane obrade tla (RT) na Fluvisole u humidnom podneblju (Hrvatska). Svaki sustav obrade podijeljen je na parcele sa i bez slame. Utjecaj je fokusiran na fizikalna svojstva tla i prinos soje (*Glycine max* (L.) Merr.). Volumna gustoća tla bila je značajno niža kod RT sa slamom u usporedbi s ostalim tretmanima. Utjecaj slame na volumnu gutoću zabilježen je i na 10-20 cm dubine. Mehanički otpor tla nije premašio vrijednost od 2.5 MPa na bilo kojem tretmanu, te je značajno smanjen na parcelama pod slamom u jesen. Sadržaj vode u tlu pokazao je veće vrijednosti na parcelama pod slamom na RT i MT. Postotak stabilnih agregata velika je na parcelama s slamom na RT I MT. Prinos zrna soje bio je veći na parcelama pod slamom na RT i MT. Iz aspekta kratkoročnih rezultata može se zaključiti da je MT i RT preporučljiva alternativa za CT zbog pozitivnog utjecaja na fizikalno stanje tla i prinos zrna.

Ključne riječi: reducirana obrada tla, slama, fizikalna svojstva tla

INTRODUCTION

Implementation of proper tillage management determines future agricultural production (Birkás et al., 2008). Tillage is recognized as the most crucial factor and the biggest consumer of energy (60%-75%) in plant farming systems (Kisić et al., 2002). Tillage is widely used for its positive effects like suppressing weeds; stable yields; forming proper physical state or conserving soil moisture. But for decades many reported adverse impacts on soil physical properties such as soil compaction, high penetration resistance, occurance of hardpan, rapid erosion, poor aggregate stability, decline of hydraulic conductivity (Birkás et al., 2008; Jug et al., 2015; Bogunović et al., 2018a; Bogunović et al. 2018b). Additionally, these authors recognized mouldboard ploughing as the greatest cause of soil degradation. In this context, more than 75% of farmers in Croatia consider the plough for primary tillage, annually (Đekemati et al., 2016). Such soil management accelerates the problem of soil organic matter depletion in agricultural fields (Bogunovic et al., 2017), occurance of compaction (Bogunovic and Kisic, 2017;) and erosion (Kisić et al., 2017; Bogunovic et al., 2020a) in the region. Therefore, the conservation tillage management needs to adapt for specific environment and soils in continental Croatia. Possible solution lies in the concept of reduced tillage and addition of straw or other mulches (Kisić et al., 2010; Busari et al., 2015). Conservation tillage in other environments is proved as a viable option for reducing soil degradation and possibly restore soil productivity (Busari et al., 2015). According to Friedrih et al. (2012), there are over 125 million hectares under conservation tillage worldwide, with projections of further growth. Main principles for this alternative sustainable production are retaining (30% or more) crop residue on the soil surface (or more than 1.100 kg/ha), minimizing soil disturbance and using wide crop rotation (FAO, 2015; Jug et al., 2017). Previous research reveals that straw residue can have positive and negative implications for crop production. Most common negatives are associated with stronger disease and pest development (Vrandečić et al., 2014; Krupinsky et al., 2002), demanding tillage and sowing (Bogunović et al., 2018a; Đekemati et al., 2019), the onset of nitrogen depression, and the need for more knowledge and acquisition of specialized machinery (Jug et al., 2008). Conversly, straw reduces negative influence of direct sunlight and rainfall on the soil (Butorac et al., 2006), evaporation, crust formation and water and wind erosion (Moldenhauer et al., 1983; Rasmussen, 1999; Birkás et al., 2013); while increase snow retention, infiltration (Lal, 1995; Paul et al., 2013; Bogunović et al., 2018a), organic matter concentration (Kienzler et al., 2012), fauna activity (Mupangwa et al., 2012) and aggregate stability (Głąb and Kulig, 2008; Špoljar et al., 2009).

Problem of yield variation with conservation tillage is reported in several studies. Conservation tillage appears to be favourable for high density crops (wheat, barley, canola), and less for spring row crops (corn, soybean) (Pospišil et al., 2002; Košutić et al., 2006; Kisić et al., 2010). However, other studies claim that yield did not differ significantly among conservation and conventional treatments (Moret and Arrué, 2007; Díaz-Zorita et al., 2002). Impact of reduced tillage and straw cover on soil properties and yields are not well understood in Croatian environment. In spite of idea that conservation agriculture is not a universal solution for all, but just guidelines for the adoption of proper management in specific environmental and pedological conditions (Giller et al., 2009) we performed an experiment to test different soil management practices. Conservation agriculture takes many forms around the globe depending on farm size, usage intensity and different tools and machinery, which ultimately makes comparison challenging (Giller et al., 2015). Hence, optimizing and designing alternative tillage management that would reduce production costs, protect soil, water resources, and preserve high yields is the primary goal of this experiment. Since early 1960, the number of papers regarding different tillage treatments with mulch under agroecological conditions found in (northwestern) Croatia is scarce. Accordingly, in this paper, we will compare the impact of tillage and straw management on soil physical properties (bulk density (BD), penetration resistance (PR), water stable aggregates (WSA), soil water content (SWC)) and crop yield.

MATERIALS AND METHODS

Study site

The research was conducted in Western Pannonian Croatia (Bašić, 2014) on the fields of the Experiment Station Šašinovec, University of Zagreb Faculty of Agriculture (45°50' N; 16°11' E; 120 m a.s.l.). It is located on the alluvial plain of the Kašina stream in humid environment (Figure 1). The mean annual temperature is 11.3 °C, ranging from 0.5 °C in January to 21.5 °C in July (1983.-2012.). The average annual rainfall is 826.4 mm (1983.-2012.), while in 2019 was 1147.5 mm.

Soil texture is silty clay loam. By national (Husnjak, 2014) and WRB Classification system soil is silty clay loam Fluvisol (IUSS, 2015). Soil is slightly alkaline (pH in KCl 7.49), with low organic matter content (2.1%), rich in available phosphorus (249 mg/kg), available potassium (214 mg/kg) and medium concentration of total nitrogen (0.20%).

Experimental design and management practices

The experimental design was established during 2018 and consists of randomized split-plot block design with three replications (Figure 1).

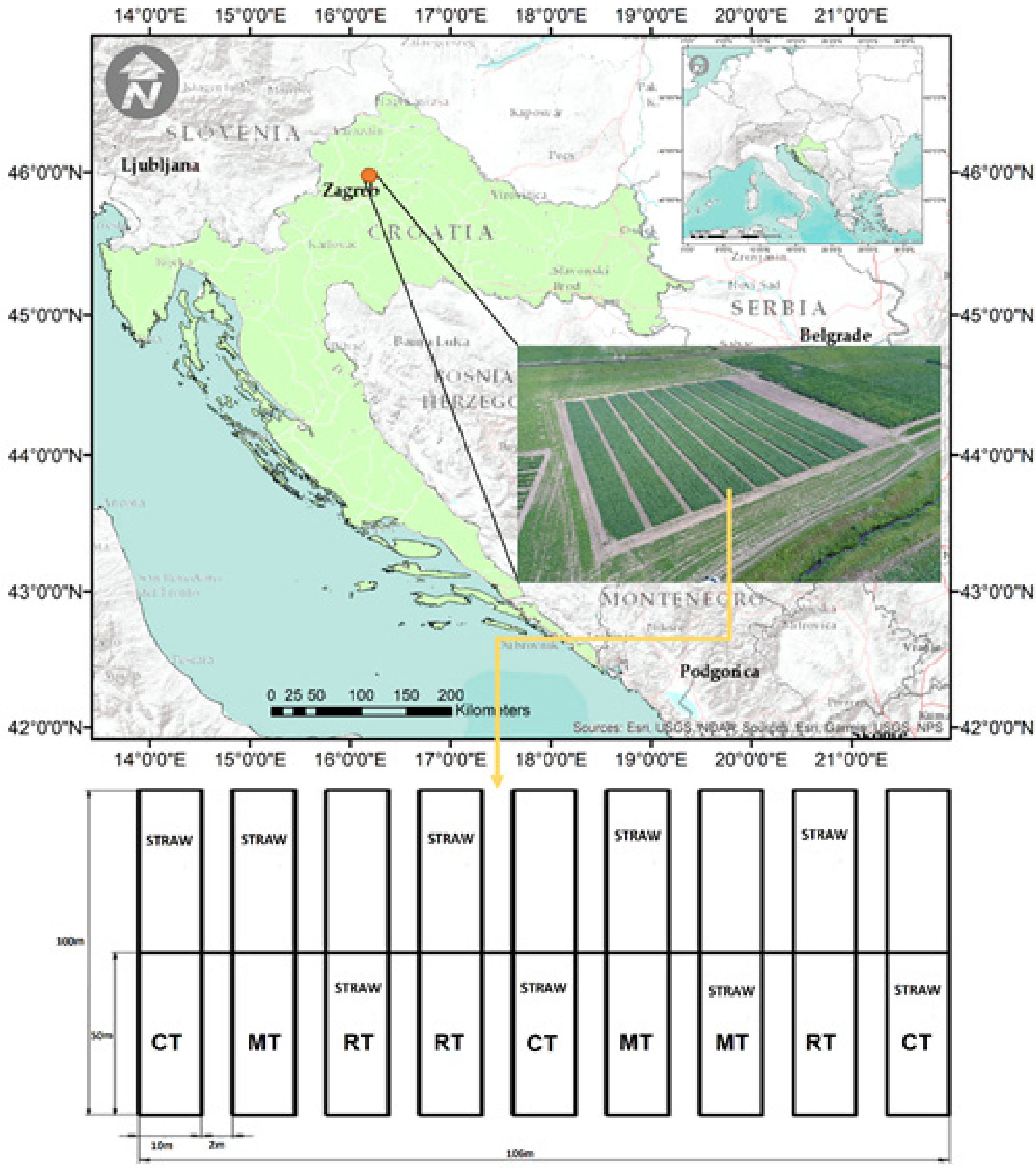

Figure 1. Study site and experimental design. CT – conventional tillage, MT – minimum tillage, RT – reduced tillage

Each block (100 m x 10 m) represents tillage management with cover as sublevel (with or no straw) (50 m x 10 m): conventional tillage (CT) - consists of mouldboard ploughing in autumn and disking and harrowing in early spring; minimum tillage (MT) – consists of multitiller in spring; and reduced tillage (RT) - includes subsoiling in autumn and multitiller in spring. Seedbed preparation was preformed across all plots uniformly. Details of important dates and information about agricultural management is presented in Table 1. Barley straw, chopped by harvester, was applied after sowing of soybean in an amount of 2.75 t/ha (≈ 140 kg per plot). The amount was selected as optimal for Croatian farmers which is above 1.1 t ha^{-1} (≈30% soil cover) set by FAO (FAO, 2015; Jug et al., 2017). Usual crop rotation on this field was soybean (2016), maize (2017), winter wheat (2017/2018). Soybean variety (2019) used for this study was AFZG Ana (maturation group 0).

Soil sampling and penetration resistance measurements

Core soil sampling (100 cm^3 cylinders) was carried out at the different treatments (tillage and straw) during June and October. In total, 108 undisturbed samples were collected per sampling date. Soil was sampled at 0–10 cm and 10–20 cm depth. The undisturbed soil samples are dried in the oven at 105 °C during 48 h in order to obtain soil water content (SWC) and bulk density (BD) according to the Grossman and Reinsch (2002). Samples (3 per treatment, 54 in total) for aggregate distribution and stability were collected at 0-10 cm soil depth. Firstly, samples were gently manipulated with fingers. Secondly, they are air-dried for several days and sieved for 30 seconds through several sieves to obtain the mass distribution (Dıaz-Zorita et al., 2002). Each fraction of aggregates was weighed to determine mean weight diameter (MWD). Water stable aggregates (WSA) in sampled soils were determined and calculated by the procedure described in Kemper and Rosenau (1986).

Table 1. Summary of agricultural management during 2018-2019 season

Operation	Information detail	Treatment		
		CT	MT	RT
Subsoiling	Mandan MGW 5 3000; working depth 35-40 cm; working width 300 cm	-	-	11 Oct 2018
Ploughing	Kuhn Varimaster 151; working depth 18-20 cm; working width 150 cm	6 Decembar 2018	-	-
Fertilization	NPK 7:14:21 (500 kg/ha)	20 April 2019	20 April 2019	20 April 2019
Disc harrowing	OLT 36 Drava; working depth 10-14 cm; working width 395 cm	24 April 2019	-	-
Multitiller	Dexwal Grunt; working depth 10-15 cm; working width 300 cm	-	24 April 2019	24 April 2019
Seedbed preparation	Maschio ASI 2; working depth 1-4 cm; working width 185 cm	24 April 2019	24 April 2019	24 April 2019
Sowing	Kverneland Accord DL300; working depth 2-6 cm; working width 290 cm	25 April 2019	25 April 2019	25 April 2019
Straw addition	2.75 t/ha (≈ 140 kg per plot)	25 April 2019	25 April 2019	25 April 2019
Plant protection	Harmony SX (7,5 g/ha) + Laguna 75 WG (70 g/ha);	7 June 2019	7 June 2019	7 June 2019
Plant protection	Pulsar 40 (1 L/ha) + Basagran 480 EC (1 L/ha)	21 June 2019	21 June 2019	21 June 2019
Harvest	Wintersteiger Nurserymaster Expert with a Harvest Master; working width 300 cm	19 October 2019	19 October 2019	19 October 2019

In close vicinity to the points where the undisturbed samples were collected, penetration resistance (PR) was measured with electronic hand-pushed penetrometer Eijkelkamp Penetrologger. The conical point was 1 cm^2 base area and the point angle was 60°. In each plot, 4 repetitions (78 per sampling date) were carried out and the value of the point corresponds to the average of these 4 measurements. Measurements were carried out at 0–10 cm and 10–20 cm.

Crop yields (three passes of harvester per plot, 54 in total) were measured during harvest and seeds were weighed after each plot and the obtained values were corrected to a 14% water content.

Statistical analysis

A factorial ANOVA design was carried out to identify differences in the BD, PR and SWC (factors: tillage, cover, season, and soil depth). For MWD and WSA, two-way ANOVA design was applied (factors: tillage and cover). One-way ANOVA was applied for soybean yield. Where ANOVA showed significant differences at $P<0.05$, a Duncan's post hoc test was applied. Statistical analyses were computed with the SAS 10.0 software package (SAS Institute Inc., 2004).

RESULTS

Rainfall pattern

The rainfall during 2019., in total, was 50% above long-term yearly mean value (826.4 mm). In the first four months, precipitation was similar as in long-term average. After that, the allocation of rainfall was fluctating for the rest of the year. May (194.5 mm), July (115.5 mm), September (163.4 mm), November (206.2 mm), December (116.2 mm) were above average while June (46.8 mm), August (54.1 mm), October (43.8 mm) were below average. During vegetation period total amount of rain was 650 mm, which is acceptable for normal growth of soybean (Pospišil, 2010).

Bulk density, penetration resistance and soil water content

Bulk density was significantly influenced by tillage (T), season (S), depth (D) and S × T, S × cover (C), T × C, S × D and T × D interactions (Table 2a). RT treatment had a significantly higher BD than CT and MT (Table 2b). At 0-10 and 10-20 cm depths, CT treatment had significantly higher BD than RT. During Autumn BD was significantly higher than during Spring period. Similar results were observed at 10-20 cm depth. Moreover, at the depth 0-10 cm BD was significantly lower than at 10-20 cm. Treatment × cover interaction was presented in Figure 2. At both covers, straw and bare, we found significantly lower BD at RT treatment than at CT and MT treatment.

Soil PR was significantly affected by tillage, depth, cover, season and S × C, T × C, S × D, T × D, C × D, S × T × C, and S × C × D interactions (Table 1a). RT treatment decrease significantly the PR compared to CT and MT. Similar results is noted at depth 10-20 cm (Table 1b). At 0-10 cm and 10-20 cm depths straw significantly reduced the PR in addition to bare plots. At both depths PR was significantly lower during Autumn in addition to Spring period. Similar to BD, PR was significantly higher at 10-20 cm depth than at 0-10 cm depth. Figure 3. presents the results of S × T × C interaction. During the Spring on bare plots (Figure 3a) CT have higher ($P>0.05$) PR in addition to RT and MT. On plots that were covered with straw we identified significantly higher PR at MT in addition to RT. During the Autumn (Figure 3b) straw was confirmed as factor which significantly reduce PR of all three tillage treatments.

Soil water content was significantly influenced by depth, T × C, T × D and S × T × D interactions (Table 1a). At 0-10 cm depth, MT treatment had a significantly higher SWC than CT (Table 1b). Significantly lower SWC was found at depth 0-10 cm in addition to 10-20 cm depth. At bare plots, tillage impacts only relatively on SWC (Figure 4), while on straw plots MT treatment showed significantly higher SWC than CT treatment. The S × T × D interaction showed significant impact only at 10-20 cm depth (Figure 5). During the Spring, CT had a significantly higher SWC than the RT.

Table 2. (a) Results of factorial ANOVA analysis for BD, PR and SWC in 2019. (b) Mean BD, PR and SWC according to the tillage practice, season, cover, and soil depth

a)		BD			PR			SWC	
Season (S)		***			***			n.s.	
Tillage (T)		***			*			n.s.	
Cover (C)		n.s.			***			n.s.	
Depth (D)		**			***			***	
S × T		*			n.s.			n.s.	
S × C		*			***			n.s.	
T × C		*			*			*	
S × D		*			**			n.s.	
T × D		*			*			*	
C × D		n.s.			*			n.s.	
S × T × C		n.s.			*			n.s.	
S × T × D		n.s.			n.s.			*	
S × C × D		n.s.			**			n.s.	
T × C × D		n.s.			n.s.			n.s.	
S × T × C × D		n.s.			n.s.			n.s.	
b)	0-10 cm	10-20 cm	Average	0-10 cm	10-20 cm	Average	0-10 cm	10-20 cm	Average
					Tillage				
CT	1.34a	1.38a	1.36a	1.05a	1.61a	1.33a	31.6b	37.7a	34.7a
MT	1.35a	1.35ab	1.35a	0.96a	1.69a	1.33a	34.8a	36.9a	35.9a
RT	1.25b	1.33b	1.29b	0.94a	1.53b	1.24b	32.3ab	35.3a	33.8a
					Cover				
Straw	1.30a	1.35a	1.33a	0.86b	1.48b	1.16b	33.3a	36.3a	34.8a
Bare	1.31a	1.37a	1.34a	1.11a	1.74a	1.43a	32.5a	37.0a	34.8a
					Season				
Spring	1.29a	1.31b	1.30b	1.17a	1.74a	1.46a	32.4a	35.8a	34.1 a
Autumn	1.33a	1.41a	1.37a	0.80b	1.48b	1.14b	33.4a	37.6a	35.5 a
Depth			1.31b			0.99b			32.9b
			1.36a			1.61a			36.7a

Statistical significances at ***P<0.001, **P<0.01 and *P<0.05. Non-significant (n.s.) at a P<0.05. Different letters represent significant (P<0.05) differences between tillage practice, soil cover, season and depth treatments. CT, conventional tillage; MT, minimum tillage; RT, reduced tillage

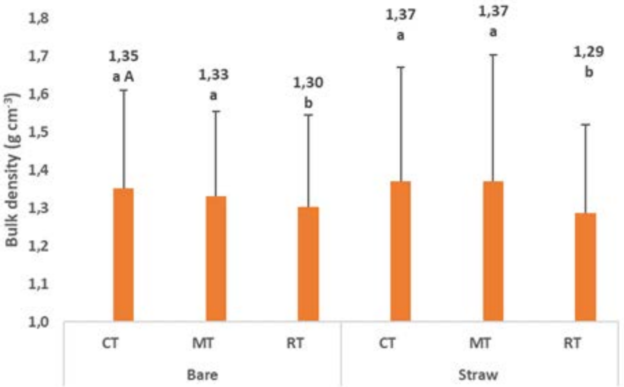

Figure 2. Effect of tillage treatments on soil bulk density according to soil cover. Different letters represent significant differences at a *P*<0.05. CT, conventional tillage; MT, minimum tillage; RT, reduced tillage

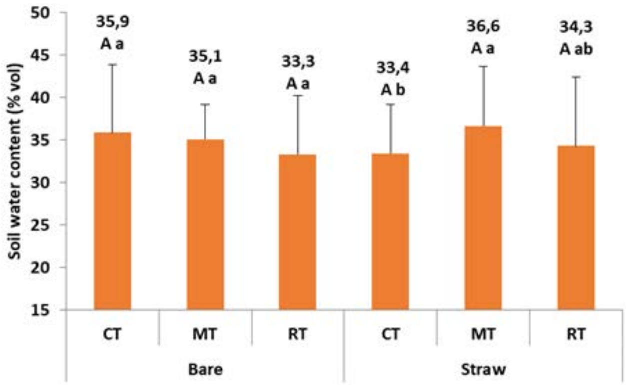

Figure 4. Effect of tillage treatments on soil water content according to soil cover. Different letters represent significant differences at a *P* < 0.05 between tillage (lowercase) and cover (uppercase) treatments. CT, conventional tillage; MT, minimum tillage; RT, reduced tillage

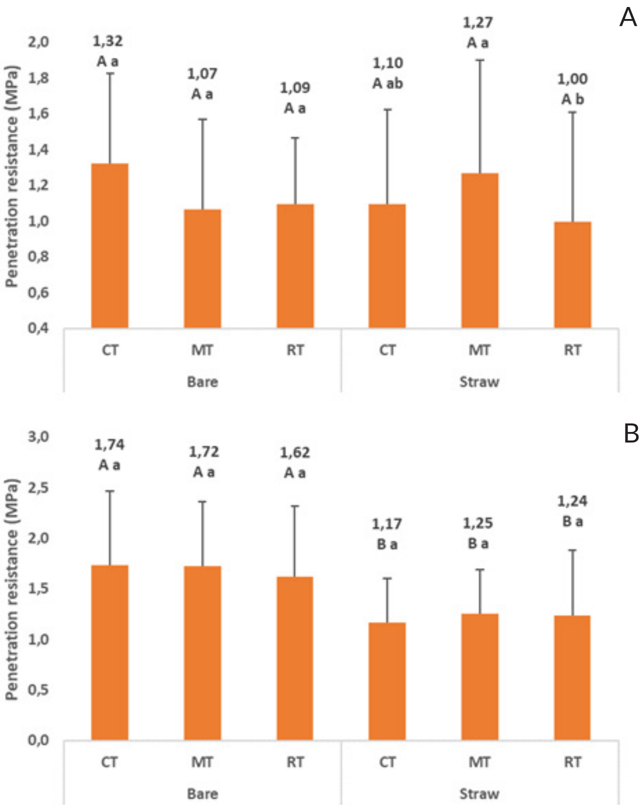

Figure 3. Effect of tillage and cover treatments on soil penetration resistance during: A) Spring and B) Autumn. Different letters represent significant differences at a *P*<0.05 between tillage (lowercase) and cover (uppercase) treatments. CT, conventional tillage; MT, minimum tillage; RT, reduced tillage

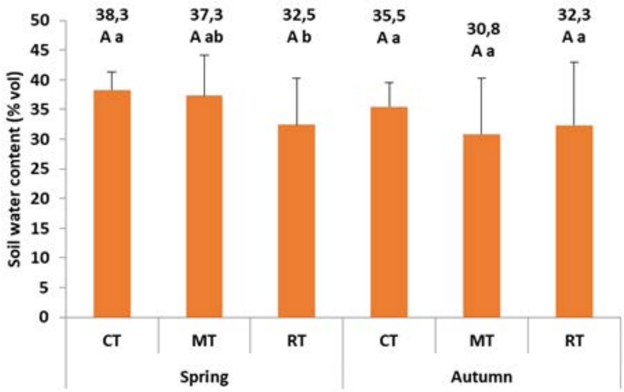

Figure 5. Effect of tillage treatments on soil water content according to season at 10-20 cm depth. Different letters represent significant differences at a *P* < 0.05 between tillage (lowercase) and seasons (uppercase) treatments. CT, conventional tillage; MT, minimum tillage; RT, reduced tillage

Aggregate stability

Results of WSA was presented in Figures 6. and 7. Although we did not identify significant differences during single factor and their interaction analysis, we have noted several trends. The highest WSA had RT, while CT had the lowest. Comparing the cover plots, straw identified higher WSA percentage in addition to bare plots (Figure 6). At bare and straw plots, both reduced treatments (MT and RT) had relatively higher values of WSA in addition to CT treatment (Figure 7).

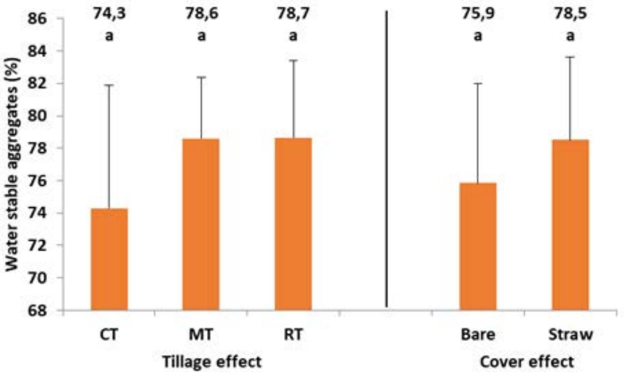

Figure 6. Single factor effect of tillage and cover on percentage of water stable aggregates. Different letters represent significant differences at a $P<0.05$. CT, conventional tillage; MT, minimum tillage; RT, reduced tillage

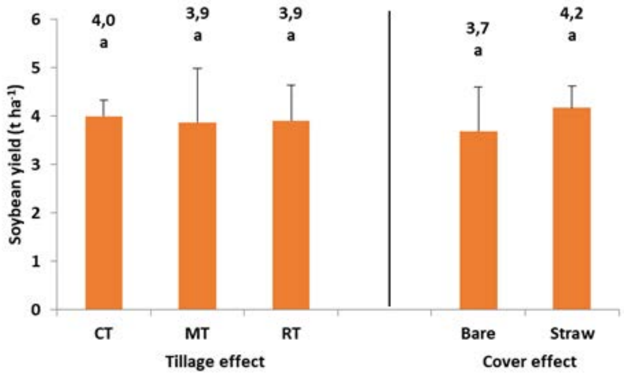

Figure 8. Single factor effect of tillage and cover on soybean yield. Different letters represent significant differences at a $P<0.05$. CT, conventional tillage; MT, minimum tillage; RT, reduced tillage

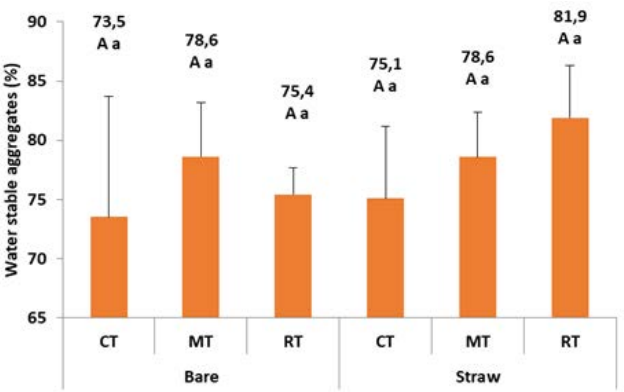

Figure 7. Interaction factor effect of tillage and cover on percentage of water stable aggregates. Different letters represent significant differences at a $P<0.05$ between tillage (lowercase) and cover (uppercase) treatments. CT, conventional tillage; MT, minimum tillage; RT, reduced tillage

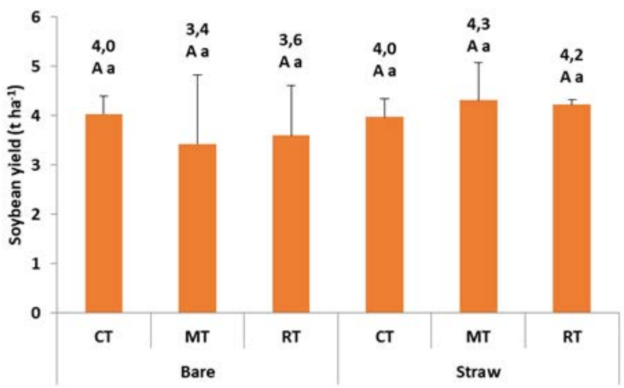

Figure 9. Interaction factor effect of tillage and cover on soybean yield. Different letters represent significant differences at a $P<0.05$ between tillage (lowercase) and cover (uppercase) treatments. CT, conventional tillage; MT, minimum tillage; RT, reduced tillage

Soybean yield

Single effect on soybean yield was shown in Figure 8., while interaction T × C in Figure 9. Significant differences were not observed in all cases. The higher soybean yield was noted at straw plots (4.2 t/ha) in addition to bare plots (3.7 t/ha). Tillage impacted on yield almost uniformly. Tillage × cover interaction reveals positive impact of straw on soybean yield on MT and RT treatments. These two treatments recorded 21% and 15% higher yields of soybean in addition to same treatments on bare plots.

DISCUSSION

Bulk density and penetration resistance measurements

Soil BD is one of the most valuable soil physical parameter (Husnjak et al., 2002; Hamza and Anderson, 2005). Results showed significantly lower BD at RT in addition to CT and MT. Similar results were noted at straw and bare plots which indicate that ripping have more benefit effect on soil BD than plowing and discing. Lower BD at ripped soils in addition to shallow tillage soils were found in other soils and environments. This could be due to differing ways of fracturing, tillage depths and number of operations. Cay et al. (2018) on clay loam soil did not found any significant difference in BD between treatments, but reported that minimum tillage treatment decreased BD for 5%, respectively. In Pakistan, Khurshid et al. (2006) reported higher BD in minimum tillage (1.47 g/cm^3) treatment followed by conventional tillage (1.41 g/cm^3) and deep tillage (1.38 g/cm^3) treatments. Additionally, Bogunović et al. (2018a) on Anthrosols found lower BD at deep tillage (disc harrow with ripping) (1.21 g/cm^3) in addition to shallow disc harrow (1.33 g/cm^3) treatments. Qamar et al. (2015) also report 5% lower BD at deep tillage treatment compared to conventional tillage on sandy clay loam soil. In present study higher BD was found at CT than at RT treatmens which is in accordance with Álvaro-Fuentes et al. (2008). Others found opposite results (e.g. Berzegar et al., 2003), while thirds report no significant differences betwenn treatments (Chaudhary et al., 1985; Logsdon and Cambardella, 2000; Sharratt et al., 2006; Bogunović et al. 2018b) indicating, very likely, the low sensitivity of BD to tillage treatments in different textured soils.

Temporal comparison showed significantly higher BD during Autumn than during Spring, which is in accordance to Singh and Malhi (2006), Blanco-Canqui et al. (2009), Bogunovic et al. (2018b) and Li et al. (2019). The lowest BD were found during Spring at RT treatment, which proves positive effect on an arable layer by destroying hardpan and ameliorating hard setting soils (Hamza and Anderson, 2005). Present results confirm the fact that arable soils have artificialy created structure by tillage, hovewer rainfall and traffic events decrease soil loose state until the end of season (Birkás et al., 2018). Straw treatments as single factor did not affect the BD, suggesting that more years is needed, and more straw application is needed to affect this soil property. These results are in agreement with Mulumba and Lal (2008), who reported that mulch have variable effect on BD due to land use, soil properties and type, climate, type and origin of mulch. On all treatments, depths and sampling periods BD was below 1.5 g/cm^3 indicating that soybean root system in medium heavy soils does not have any problems for growth and development (Lhotský, 1991), which is confirmed on silty loam (Filipovic et al., 2006) and for silty clay loam (Hanks and Lewandowski, 2003) soils.

Penetration resistance and BD were measured at the same time, as together these factors significantly determine soil compaction (Unger and Jones, 1998) and regulate the depth of the hardpan within the solum (Birkás et al., 2004). The results of BD and PR as single factors were similar. The PR was low in RT and higher in MT and CT, as is reported in previous works (e.g. Đekemati et al., 2019). During the Autumn, interaction results indicate significantly higher PR at MT in adition to RT treatment on straw plots as is reported in Arvidsson et al. (2013) and Bogunovic et al. (2020b). Meanwhile, during the Autumn, straw significantly decrease PR in addition to bare plots at all treatments indicating conservation possibilities of the straw on SWC (will be discussed below) as is noted in other studies. Absence of difference between straw and bare plots is probably because straw mulch was recently applied before sampling and measurement. Topsoil without the cover of organic or plastic mulch is under greater evaporation which leads to lower SWC and higher PR (Fuentes et al., 2009; Qamar et al., 2015).

Finally, according to Taylor (1971) the 2.5 MPa is the threshold for stopping root penetration. Furthermore, Jug et al. (2015) consider values below 2.5 MPa as favourable soil condition for crop production. Altogether, non of the treatment did surpass 2.5 MPa, so there was no potential negative effect on the root.

Rainfall pattern and soil water content

During the vegetation period, several extreme rainy months (May, September) and extreme dry months (June, August and October) occurred. According to Jug et al. (2015) months that have 35% more rainfall than multi-year average is considered extremely rainy, and those with 35% less rainfall than multi-year average are extremely dry months. Unfortunately, extremes in rainfall distribution in Central (Bogunovic and Kisic, 2013) and NW (Šestak et al., 2012) Croatia were already noted. Still, the year 2019 was classified as rainy (wet) by Croatian Meteorological and Hydrological Service (2020).

Results of single factors show absence of significant differences between treatments and subttreatments, although the relatively higher SWC was noted at straw plots in addition to bare one. Such results indicate that under humid and semihumid conditions tillage treatments rarely shows benefit of soil conservation possibilities like it is reported in other studies (e.g. McVay et al., 2006; Kováč et al., 2005). While sampling during humid conditions minimizes the effect of straw on SWC accumulation. More research is needed to understand better the treatment-straw-crop-wheather effect of soil water dynamics. However, interaction factor results indicate significantly lower SWC at RT than at CT in Spring period, and at straw subplots significantly higher SWC at MT than at CT. Other studies showed opposite. On bare plots deeper, conventional tillage under greater precipitation results in higher SWC during the season (Bogunovic et al., 2018b), but subsoiling did not have a favourable effect on SWC in present study. On silty clay loam in a two-year experiment, Kanwar (1989) also did not found any significant differences between conventional and reduced tillage systems. Moreover, in present study on both sampling times, straw treatments showed higher SWC when compared with plots without straw, but significant difference was noted only in Spring (Figure 5). This is in agreement with Sławiński et al. (2012) who on Eutric Fluvisol report greater SWC at reduced tillage with straw than at conventional ploughing treatments with straw.

Distribution of aggregates size and stabilty

Every aspect of agricultural production requires persisting soil structure. Achieving favourable soil structure and stability should always be one of the primary goals. In other soils and environments reduced tillage and straw mulch as practice has been proved for increasing aggregate stability (Stătescu et al., 2013; Beukes and Swanepoel, 2017). Present results are in agreement with this fact, although only relative differences were noted as in higher WSA at RT and MT in addition to CT, while straw also show relatively higher WSA in addition to bare plots. Interaction effect showed better structure on MT in bare plots and better structure on RT on straw plots. Thus, possibly indicating that less intensive and non-invertive tillage increases the WSA. Less frequent tillage does not expose the aggregate to the air and mineralisation of organic matter as binding agent for aggregate stability (Birkás et al., 2008), while straw addition helps to increase organic mater content and preserves the aggregate destruction from raindrop kinetic energy (Tisdall and Oades, 1982). Nyamangara et al. (2014) report that the effect of minimal tillage with mulching significantly increased WSA for 9% in clay soils in adition to conventional tillage.

Soybean yield

Soybean occupies more than 80 000 ha of agriculture land in Croatia and is one of the fastest-growing crops due to quality and market demand. Results for crop yield did not differ significantly overall. Same lack of significance for soybean was reported by Alvarez and Steinbach (2009) and Naab et al. (2017) in humid environments. However, some treatments (RT and MT) showed relatively higher yields due to the use of straw mulch. This can be explained with a reduction in SWC during summertime when straw cover on soil resulted in an increase of water retention capacity coupled with low evaporation that resulted in higher yields. A similar effect was noted by Bogunović et al. (2018b) in Pannonian Croatia, DeFelice et al. (2006) in Northern America and Xiao et al. (2019) on Chinese Loess Plateau. Furthermore, RT has a similar negative effect on crop yield as no-tillage (Pittelkow et al., 2014) which can be noted at bare plots in this study, but reduced tillage systems MT and RT with straw mulch resulted in higher yield (25%; 20%) in comparison to plots without straw (Figure 8). This effect has been noticed by Dossou-Yovo et al. (2016) and Lin et al. (2016). Also, straw cover provided 15% higher yield (Figure 8). Interestingly, when conventional tillage plots were analyzed, there was no influence of mulch on yield. To highlight, the combination of RT systems and straw as a sustainable system can be a possible solution for mitigating climate change effect on yield. In long-term studies, reduced tillage has achieved significantly higher yields (Anken et al., 2004; Šíp et al., 2013). It is important to point out that mulch can have variable responses to yield (Wicks et al., 1994). For example, Gajri et al. (1994) on loamy sand report that mulch increases yield, while in sandy loam some yields varied depending on the year.

CONCLUSION

RT tillage had lower compaction BD and PR values than CT and MT treatments. Straw significantly decrease the PR, and relatively increase the SWC, indicating that one year and one application is too short period and too low dose to have greater positive impact on soil physical state. In this context, CT, retained more water than other treatments. Intensive, invertive tillage decrease the aggregate stability in addition to MT and RT, while mulch increase the structure stability at all plots. Such results indicate that straw mulch and reduced tillage is worthy practice that should be monitored in long term and different years as it can be potentionaly crucial factor for minimizing soil degradation. For the short-term experiment on silty clay loam soil in humid condition, it can be concluded that the best practice in plant production is the application of straw and low tillage/traffic intensity, such as in MT. Supporting this research for long-term and continuous monitoring of soil physical parameters and yield, but with further research of economic expenses and CO_2 emissions will provide better background and acceptance of farmers.

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